THE 1996 CANYONLANDS INITIATIVE: FIELD STUDY OF SMALL PLANETARY GRABENS. J. M. Moore[1] R. A. Schultz[1], E. B. Grosfils[2], A. N. Fori[1], W. H. Roadarmel[1], N. I. Bush[2], C. Harris[2], and C. B. Ivers[3], [1]Geomechanics-Rock Fracture Group, Department of Geological Sciences, Mackay School of Mines, University of Nevada, Reno NV 899557-0138, USA (http://unr.edu/homepage.schultz; schultz@mines.unr.edu), [2]Department of Geology, Pomona College, Claremont CA 91711, USA (egrosfils@pomona.edu), [3]Department of Geosciences, University of Massachusetts, Amherst MA 01003, USA.

Summary: An integrated field investigation of the grabens of Canyonlands National Park was carried out in August 1996. Representatives from four universities focused on three main tasks: (1) investigation of joint-fault relationships near ramps at graben terminations, (2) using seismic refraction to complement structural studies, and (3) evaluation of graben-widening mechanisms. Our results suggest that graben formation in a lithologic sequence having sharp rheologic contrasts can be more complicated than simple keystone collapse of wedge-shaped blocks.

Introduction and Background: The grabens in Canyonlands National Park [1,2] provide a unique opportunity to study in detail the processes of graben formation, growth, and interaction using morphologically fresh and actively growing examples. These structures are commonly cited as terrestrial analogs to small grabens that are both common and kinematically important on many planetary bodies including the Moon [3], Mars [e.g., 4], Venus [5], and icy satellites of the outer planets [6]. Our ongoing studies of the Canyonlands grabens [7–9] are demonstrating that subtle asymmetric geometries in cross-section and map-view fault geometries better characterize the shape, and therefore the kinematics and mechanics, of these grabens than previous suggestions of symmetric geometry and simple upward fault propagation.

Initial results from our structural study of the grabens have been published and discussed in detail elsewhere [7] and the rock-engineering investigations of wall stability [10] are also being continued to refine our understanding of the interesting morpholigic processes along graben walls.

Our geologic investigations focused on two aspects of graben mechanics: characterization of graben-fault terminations, and broadening our studies of graben asymmetry [7] to other examples in the Park. We found that the graben-bounding faults can extend to some distance beyond the ramp areas, defining the near-tip slip profile. While this relationship is not unexpected given that the faults build up displacement by propagation of slip patches along the preexisting joints [1,7], we have now documented this interesting and important aspect of graben mechanics in the field. Ongoing work will precisely map out the displacement variation in the ramp region so that the relationship between ramp geometry and graben interaction and linkage can be analyzed.

Seismic Refraction Experiment: In addition to studying structural deformation exposed at the surface we are collecting data to characterize the subsurface geometric configuration of a medium-sized graben, Devils Lane, using seismic refraction [8]. In the initial phase of our study, two 40-m lines were placed in an X-shaped configuration near each end of the graben, while 200-m lines were used closer to the graben center. Using a sledgehammer for energy and multiple stacks to improve the signal-to-noise ratio, data were collected for each line. These data allow us to constrain the depth to bedrock and, in places, the dip of the subsurface graben floor. This information is critical to our understanding of how the Canyonlands graben system in general, and Devils Lane in particular, was formed.

By obtaining the thickness of the graben fill and combining it with surface measurements, we are able to constrain dip-slip displacement as a function of distance from the fault tips (Fig. 1). Our data indicate that dip-slip displacements near the ends of the fault are close to what is expected for a normal fault of this length. Nearer the center, however, where only a minimum depth constraint is currently available, observed dip-slip displacement is greater than that expected for a fault of this length. In fact, because fill thickness near the center of the graben exceeds 60 m (previous estimates suggested 10 m), displacement near the center of the fault (40 m above the surface, 60+ m below the surface) is now known to be at least twice as great as that predicted previously (50 m [e.g., 11]). This difference suggests that we may need to re-evaluate proposed mechanisms for graben formation.

Due to the absence of a refracted signal near the center of Devils Lane, the dip of the graben floor remains poorly constrained overall, and thus it is not yet possible to use dip data to discriminate between competing models that attempt to explain formation of the graben system in Canyonlands National Park. Graben floor dips near the ends of the east-dipping master fault, however, are now known for Devils Lane. Near the north end of the graben, the floor dips 8° ± 2° toward N76W, approximately perpendicular to the axial strike of the graben, while near the southern end of the fault the graben floor is essentially horizontal. Continued collection of seismic data is required to place better constraints upon formation of the graben system.

Conclusions: This continuing project is refining our understanding of the grabens as planetary analogs. We now suspect that graben walls retain their near-verticality as they

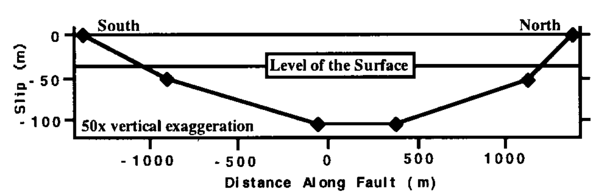

Fig. 1. Along-axis cross section showing dip-slip displacement as a function of total fault length for the Devils Lane graben. The two 100-m slip values shown are minimum displacement values, as no bedrock regraction was detected at these localities.

erode back due to the interaction between orthogonal regional joints and stratigraphy. Thus this particular case may not strictly apply to graben wall erosion on other planets unless similar conditions exist. The slip distribution along graben faults in Devils Lane is quite similar to that determined along other terrestrial normal faults and grabens, with slip minima near graben ends and maxima near their centers.

We infer that these grabens provide important new clues to how grabens work on other planets. In particular, it is likely that narrow grabens on the Moon, Mars, Venus, and Ganymede may not be fully symmetric, implying a combination of upward and downward fault propagation as well as along-strike growth and interaction.

Acknowledgments: We thank Josh Massie and Matt Soby (California State University, Fresno) and Jonathan Hinrichs (National Park Service) for joining us in the field and for their help with trip science and logistical support. Access and assistance by the Park Service is also gratefully acknowledged.

References: [1] McGill and Stromquist (1997) *JGR, 84*, 4547–4563. [2] Trudgill and Cartwright (1994) *GSAB, 106*, 1143–1157. [3] Golombek (1979) *JGR*, *84*, 4657–4666. [4] Tanaka et al. (1991) *JGR, 96*, 15,617–15,633. [5] Ivanov and Head (1996) *JGR, 101*, 14,861–14,908. [6] Golombek and Banerdt (1986) *Icarus, 68,* 252–265. [7] Schultz and Moore (1996) in *Geology and Resources of the Paradox Basin,* Utah Geol. Assn. Guidebook, 25, 295–302. [8] Bush et al. (1996) *Eos, 77,* F643. [9] Moore and Schultz (1996) *Eos, 77,* F643. [10] Fori et al. (1996) *Eos, 77,* F643. [11] Cartwright et al. (1995) *JSG, 17*, 1319–1326.

Fig. 2. Participants in the 1996 Canyonlands Initiative. Standing, from left to right, are Jonathan Hinrichs, Richard Schultz, Josh Massie, Jason Moore, Eric Grosfils, Will Roadarmel, Nathaniel Bush, and Matt Soby. Seated, from left to right, are: Caroline Harris, Andrea Fori, and Carol Ivers. Photo by Matt Soby.